JOINT FACILITY LOCATION—HANDLING SYSTEM SELECTION WITH INVESTMENT CONSTRAINT

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CERTIFICATE

Certified that the thesis entitled "Joint Facility Location - Handling System Selection With Investment Constraint" by Kamlesh Mathur has been carried out under my supervision and that it has not been submitted elsewhere for a degree.

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A recurrent problem in industries is that of locating new facilities and the selection of materials handling equipments for moving materials between the various locations. The problem can occur at various levels of complexities. In the past, most of the investigators have tried to solve the problem of location and materials handling equipment selection as two independent problems. However, it is a well known fact that the selected materials handling equipment influences the facility location and hence the layout of the shop. In the present work, therefore, an attempt is made to solve the problem of facility location and handling system selection in an integrated manner. Two alternate approaches are proposed. Fist approach uses ZERO-ONE procedures where as in second approach, the problem is structured as multistage sequential decision problem and

is solved using dynamic programming procedure. A method to overcome the dimensionality problem in the dynamic programming procedure has also been suggested.

A number of problems have been solved using both the approaches. It is found that computation time required to solve a given problem by dynamic programming procedure is much more than that required by the Zero-one programming procedure. However, the extra information obtained in a single computation run of dynamic program outweighs the additional time required.

Both procedures give optimal solution, nevertheless there are limitations to each of the proposed methodologies. Large memory location requirement in dynamic programming procedure has restricted its application to problems of 5 to 6 flow paths and two types of material handling systems that can be shared by two or more flow paths. However much larger problems can be solved using zero-one programming procedure. A problem involving 3 new machines, 9 flow paths and 4 alternate materials handling systems has been solved using 0 - 1 programming procedure in around 30 minutes of computer time on IBM 7044/1401 system.

CHAPTER I

INTRODUCTION AND LITERATURE REVIEW

In the overall spectrum of manufacturing management, plant layout and materials handling plays a vital role. The productivity and the cost of production of a company are very strong functions of its location, the layout and materials handling methodology. It is interesting to point out that for every ton of finished goods that go out of a factory door, atleast fifty tons must be lifted or carried around the plant to produce it, upto 80% of all indirect labour cost in a plant and nearly one half of the total cost of manufacturing can be attributed to materials handling. To gauge the importance further, atleast one rupee out of every ten rupees the industry spends on plant improvement today goes to the purchase and maintenance of materials handling equipment. The above figures are enough to reflect the importance of layout and materials handling and emphasise the fact that a saving of a small fraction of materials handling cost here and there is a significant total cost reduction.

Materials handling and plant layout are so closely interwoven that it is difficult to distinguish between them. It is impossible to install an effective handling system without considering the plant layout and vice-verca. One of the widely faced and a bit neglected class of layout problem is the Revising and Improving of Existing Plant Layout. To maintain operating efficiency over a period of time,

a given plant layout must ordinarily be modified and improved in some way. Even in a newly constructed plant, management may find it necessary to make revisions in both the process and layout because of rapid technological advances and unforeseen changes in demand. The dynamic nature of competitive industry therefore, compels progressive management to make layout changes for various reasons. Some of these reasons are as follows :

1. A plant layout may be revised (for expansion in production capacity) to meet a relatively permanent increase in the demand for its products. Such expansion may involve providing facilities for the production of new products. This may require the addition of new facilities to the plant or the conversion of existing unused facilities to the output of new related products.

2. A plant layout may be revised to attain greater competitive efficiency by adopting various technological improvements that effect the plant and its operation. Such advances include improvements in product design.

3. Plant layout revisions may be the result of work-simplification programs that improve production processes and layout arrangements.

The most frequently occuring layout modification is due to expansion in production capacity which requires the addition of new

facilities to the plant. Depending upon the situation there might be a considerable material flow between the new and existing facilities and also among the new facilities, involving significantly large materials handling cost. By making a judicious allocation of new machines and proper selection of material handling equipment, this materials handling cost can be minimized.

Inspite of the fact that optimum location of facilities would yield considerable amount of cost reduction, only a few methodologies have been developed and reported in the literature. A review of the literature available in this area is presented in the following section.

1.1 LITERATURE REVIEW

The literature on the subject is sparse and in the past, investigators have primarily been concerned with the trial and error solutions {1, 2}. The first analytic technique was reported by ANDRE E. BINDSCHEDLER and JAMES M. MOORE {3} in 1961. They considered the continuous location problem of locating a single new machine in an existing plant. The proposed graphical technique consists of drawing level curves (Iso - Cost Curves) for the entire plant and choosing the suitable location on the minimum cost curve. The technique, however, was restricted to only one new machine.

WIMMERT {4} and CONWAY {5} also examined this problem but limited themselves to discrete candidate locations. They assumed

that the new machines will have no interaction, in terms of materials flow, with the existing machines. This situation is certainly possible, but rather seldom found in practical cases.

JAMES MOORE [6] contradicted the WIMMERT - CONWAY view, and developed assignment model which considers that all new machines will have materials handling contact with the existing machines. Discrete candidate areas for locating the new machines were still used and no flow of material among the new machines was considered. The proposed technique uses "Hungarian Method for Assignment Problem" for locating the new machines.

It needs to be pointed that in all the above reported literature except Conway's and Wimmert's work, no flow of material between the new machines has been considered. FRANCIS [7, 8] has tried to extend MOORE'S level curve technique for this case but his analysis holds good only for one dimensional cases, i.e., all the existing and new machines are in a straight line. Moreover, the analysis turns out to be quite complex for more than two new machines. This method can also be extended to two dimensional case when the flow of material is equal in all flow paths. However, this is quite an impractical situation.

Another work reported with flow among the new machines is due to ROGER C. VERGIN and JACK D. ROGERS [9]. They have given an analytical algorithm for Moores level curve technique for single new machine by using minimal property of the median. This algorithm

assures optimal solution which may be unique or lie within a range. For the case of locating several new facilities, Vergin and Rogers have instituted a computer search process comprising the following three major steps :

1. Each new machine in turn is located at a temporary optimum point assuming other m + n - 1 (m = number of existing machines, n = number of new machines) machines fixed at their current locations.

2. After all n new facilities are located in this manner, the process is repeated.

3. Readjustment process is continued until no further movement occurs during a complete round of adjustment evaluations.

At each step in the above process, the computer subroutine for single machine was used to find the temporary optimum location. The proposed search procedure is computationally fast but does not assure the optimal allocation.

WILLIBOUGH {10} in his unpublished M.S. work has given a dynamic programming approach for joint facility location and equipment selection problem. He suggested that materials handling cost very much depends upon the type of materials handling equipment used for particular flow path, hence the problem of locating new machines and selecting suitable materials handling equipment for each flow

path should be considered simultaneously. In structuring this problem as a multistage sequential decision problem, each new machine and the corresponding flow paths are considered as the stages while the number of potential locations available for the new machines are treated as state variables. Material handling systems and material-handling costs are considered as decision variables and return function respectively. This approach gives optimal solution for the situations having no budgetory constraint for the purchase of materials handling equipments. When the investment constraint is introduced, the algorithm gives sub-optimal solutio Which sometimes might be quite far from the optimal solution (10).

1.2 PRESENT WORK

Realizing the importance of facility location with reference to cost reduction programme and recognizing the fact that no good approaches are available in the literature to handle practical facility location and materials handling problem in an integrated manner, the present work has been undertaken.

The present investigation is in line with Willibough's work and two methodologies are proposed for finding overall optimum solution of Joint Facility Location - Handling System selection problem with budgetory constraint.

CHAPTER II

PROBLEM DEFINITION AND FORMULATION

2.1 PROBLEM DEFINITION

As mentioned in the previous chapter, the objective of the present work is to find an analytical solution procedure for a Joint Facility Location - Handling Equipment Selection problem. The problem can more explicitly be stated as follows :

"For an existing plant, the management has taken a decision to add some new machines, may be to meet permanent increase in demand. There is flow of materials between the new and existing facilities and also among the new machines. For every machine pair having materials flow, there may be a number of alternate materials handling systems that can be used to transfer the materials. The objective is to determine simultaneously the optimal locations for the new machines and the optimal materials handling equipments to be used among the various machine pairs so as to minimize the total materials handling cost subjected to the condition that the investment on the new materials handling equipments does not exceed the available finances."

2.2 ASSUMPTIONS

The problem as stated is quite complex in its overall spectrum and an analytical solution for this generalized case seems to be impossible. However, by making some judicious assumptions the

problem can be simplified. The assumptions are introduced without affecting too much the practical features of the problem. The main assumptions are :

1. DETERMINISTIC FLOW OF MATERIAL

For the present analysis inter-facility materials flow is idealized to be deterministic, which is not strictly true. This assumption is introduced on the grounds that if the planning data are accurate, small imbalances due to variable flow will resolve themselves in the long run.

2. DISCRETE LOCATIONS

Facility location problem can be handled using either discrete or continuous locations. If a grid was to be superimposed over an existing plant layout, the new machines which themselves are considered as point locations, could be located only at the intersection of the grid lines in the candidate area. A continuous location problem would exist if the new machine could be located anywhere with in the candidate area, i.e., between the grid lines as well as on them. When a new plant is to be built, the only layout restriction is the building configuration. Therefore, in such cases continuous locations make more sense than discrete candidate areas. However, when new machines are to be fitted "in to" the existing plant layout, constraints due to building configuration and present set up result in only a few discrete potential locations.

3. OTHER ASSUMPTIONS

A few other logical assumptions are :

(a) Materials handling costs are directly proportional to the distance moved.

(b) The materials handling cost per unit of distance are the same for a particular handling system for all machine-pairs irrespective of the direction of materal flow.

(c) Between a machine-pair only one type of handling system is used.

(d) Wages of the materials handling equipment operators are not included in the present formulation.

2.3 FORMULATION : ZERO - ONE PROGRAM

For the problem defined in Section 2.1 and with aforementioned assumptions, two alternate approaches are proposed. This section deals with the ZERO - ONE programming formulation where as in Section 2.4 a dynamic programming approach is presented.

2.3.1 Definitions

(a) FLOW PATH : Any facility-pair having materials flow between them is termed as a flow path.

(b) LOCATION COMBINATION : Any feasible assignment of new facilities to the potential locations is termed as a location combination.

2.3.2 Notations

N_1	Number of new machines
N	Number of potential locations.
M	Number of existing machines.
LC	Total number of possible location combinations.
F	Total number of new flow paths.
I	Suffix for flow path.
J	Suffix for alternate materials handling system.
K	Suffix for location combination.
P	Set of all J's.
P1	$P1 \subset P$ comprising those J's for which corresponding materials handling system can be shared by two or more flow paths e.g., handling trucks.
P2	$P2 \subset P$ comprising all J's for which the corresponding handling system can not be shared by more than one flow paths, e.g., conveyors.
A (I, J, K)	Fraction of Jth ($J \in P1$) type of handling equipment required for Ith flow path with Kth location combination.
X (I, J, K)	A 0 - 1 variable which is : 1 If Jth handling system is used for Ith flow path with Kth location - combination. 0 Otherwise.
C (I, J, K)	Material handling cost incurred if Jth handling system is used for Ith flow path with Kth location combination.

E (I, J, K)	Purchase cost of Jth handling system ($J \in P2$) for Ith flow path with Kth location combination.
PC (J)	Purchase cost of Jth handling system ($J \in P1$).
S (J)	Unused capacity of Jth type of handling system in the present layout.
G	Maximum investment for the purchase of handling equipments.
Y (J, K)	Number of Jth type ($J \in P1$) of handling equipment required with Kth location combination.

2.3.3 Formulation

For a particular location combination K, the various constraint equations are :

1. HANDLING SYSTEM SELECTION CONSTRAINT

It is desired to use only one type of handling system for a particular flow path. Mathematically, for each flow path, this constraint can be expressed as :

$$\sum_{J \in P} X(I, J, K) = 1 ; \qquad I = 1, F \qquad (2.1)$$

2. INVESTMENT CONSTRAINT

Jth ($J \in P1$) type of handling system is always bought in whole numbers, though the requirement may be in fractions, e.g., if 3.6 fork trucks are needed, then 4 (higher integer value) trucks have to be purchased. This can be acertained by adding following constraint for Jth type of handling system ($J \in P1$).

$$\sum_{I=1}^{F} A\ (I,\ J,\ K)\ .\ X\ (I,\ J,\ K) - Y\ (J,\ K) \leq S\ (J)\ ;\ \text{all } J,\ J \in P1 \tag{2.2}$$

Where Y (J, K) is an integer and gives the number of Jth type of handling equipment required for Kth location combination.

The investment constraint then can be written as :

$$\sum_{I=1}^{F} \sum_{J \in P2} E\ (I,J,K)\ .\ X\ (I,J,K) + \sum_{J \in P1} Y\ (J,K)\ .\ PC\ (J) \leq G \tag{2.3}$$

3. OBJECTIVE FUNCTION

The optimization criterion is to minimize total materials handling cost. The objective function can therefore, be written as :

$$\text{Min}\quad Z\ (K) = \sum_{J \in P} \sum_{I=1}^{F} C\ (I,J,K)\ .\ X\ (I,J,K) \tag{2.4}$$

Equations 3.1 to 3.4 form a pure integer program in which X (I,J,K) are 0 - 1 variables where as Y (J,K) can take any integer value. Y (J,K), however, can be represented as a sum of 0 - 1 variables. To illustrate, suppose a variable Y (J,K) has a determinable upper bound U. Then, wherever Y (J,K) appears an equivalent binary representation can be substituted.

$$Y\ (J,K) = 1\ \omega_1\ (J,K) + 2\ \omega_2\ (J,K) + \ldots + 2^{q-1}\omega_q\ (J,K) + \ldots + 2^{l-1}\omega_l\ (J,\ K) \tag{2.5}$$

Where ω_q = 0 or 1 and value of l is choosen such that $2^{l-1} \geq U$.

Combining equation 3.5 with equations 3.1 to 3.4 a pure 0-1 program is obtained for the Kth location combination. There will be in all a total of 'LC' such programs and the overall objective therefore, is to find that value of K and corresponding X (I, J, K) for which the total materials handling cost is minimum, i.e.,

$$\min_{K = 1, LC} Z(K) \tag{2.6}$$

2.4 DYNAMIC PROGRAMMING FORMULATION

2.4.1 General

Using the dynamic programming strategy to solve the facility location - handling system selection problem requires that it first be recognized as a multistage, sequential decision problem. This implies that two types of variables, namely state variables and the decision variables together with stages and performance criterion have to be first identified.

STAGES : Each new facility as well as each flow path is considered as a stage. A new facility will be called a major stage and the corresponding flow paths are termed as minor stages.

STATE VARIABLES : For simplicity in structuring the problem and subsequent formulation, two directional state vectors are introduced, i.e., state vector X in the horizontal direction and Y_J in the vertical direction.

Vector $X = (x_o, x_1, \dots x_s)$ is a $(S + 1)$ dimensional vector. The element x_o represents the finances available for the purchase of handling equipments and x_i, $i = 1, S$ is the fraction of ith handling system available.

$Y_J = (y_1, \dots, y_J)$ gives the location combination of the J facilities.

CONTROL OR DECISION VARIABLES : Alternate materials handling systems are considered as the decision variables.

PERFORMANCE CRITERION : Materials handling cost is taken as the performance criterion which determines the effectiveness of a given decision.

2.4.2 Notations

I	Suffix for the major stage.
J	Suffix for the minor stage
S	Number of alternate materials handling systems.
P	Set of all materials handling systems.
P1	$P1 \subset P$ set of all materials handling systems which can be shared by two or more flow paths.
P2	$P2 \subset P$ set of all handling systems which can not be shared by two or more flow paths.
U (I, J)	Set of all admissible handling systems for Jth minor stage of the Ith major stage.
u	Decision variable $(u \in U)$.

PC (u, Y_I, I, J)	Purchase cost of uth handling system for Jth minor stage of the Ith major stage ($u \in P2$).
PC (u)	Purchase cost of the uth handling system ($u \in P1$).
MHC (u, Y_I, I, J)	Material handling cost for the Jth minor stage of the Ith major stage if the uth material handling system is used with location vector Y_I.
MHR (u, Y_I, I, J)	Fraction of the uth handling equipment required for the Jth minor stage of the Ith major stage, with location vector Y_I.
G_X, G_Y	State transformation function for X and Y directional states respectively.
X	State vector in horizontal direction.
Y_I	State vector in vertical direction for the Ith major stage.
F (X, Y_I, I, J)	Optimum handling cost for all the flow paths of (I - 1) facilities and J flow paths of Ith facility with resource vector X and location vector Y_I.
MHC (u, X, Y_I, I, J)	Materials handling cost for the Jth minor stage of the Ith major stage if the uth handling system is used with state vectors X and Y_I in horizontal and vertical directions respectively.
K (I)	Number of minor stages in Ith major stage.
ΔX	State increment vector.

2.4.3 Formulation

Using the notations of the previous section, the recursive relation can be written as :

$$F(x, Y_I, I, J) = \min_{u \in U} \Big\{ MHC(u, X, Y_I, I, J) + F(G_X(X), G_Y(Y_I, J), I, J - 1) \Big\} \quad \text{if } J > 1$$

$$= \min_{u \in U} \Big\{ MHC(u, X, Y_I, I, J) + F(G_X(X), G_Y(Y_I, J), I - 1, K(I - 1)) \Big\} \quad \text{if } J = 1 \qquad (2.7)$$

The iteration begins by specification of the minimum cost function at the first minor stage of first major stage.

$$F(X, Y_1, 1, 1) = \min_{u \in U} \Big\{ MHC(u, X, Y_1, 1, 1) \Big\} \qquad (2.8)$$

$MHC(u, X, Y_I, I, J)$ for equations 2.7 and 2.8 can be stated as follows :

If $u \in P1$

$$MHC(u, X, Y_I, I, J) = MHC(u, Y_I, I, J) \quad \text{If } MHR(u, Y_I, I, J) < x_u \text{ Or } PC(u) \leq x_o$$

$$= \infty \quad \text{Otherwise} \qquad (2.9)$$

$u \in P2$

$$MHC(u, X, Y_I, I, J) = MHC(u, Y_I, I, J) \quad \text{If } PC(u, Y_I, I, J) \leq x_o \qquad (2.10)$$

$$= \infty \quad \text{Otherwise}$$

State transformation function G_X and G_Y are defined as :

$$G_Y(Y_I, J) = (y_1, y_2, --- y_{I-1}) \quad \text{If } J = 1 \text{ and } Y_I = (y_1, y_2, \ldots y_{I-1}, y_I)$$

$$= Y_I \quad \text{if} \quad J > 1 \qquad (2.11)$$

If $u \in P1$ then

$$G_X(X) = (x_o, x_1, \ldots x_u - MHR(u, Y_I, I, J) \ldots x_s) \text{ if } MHR(u, Y_I, I, J) \leqslant x_u$$

$$= (x_o - PC(u), x_1, \ldots, x_{u+1} - MHR(u, Y_I, I, J) \ldots x_s)$$

$$\text{if } MHR(u, Y_I, I, J)\ x_u \text{ and } PC(u) \leqslant x_o. \quad (2.12)$$

$$= \emptyset \quad \text{otherwise.}$$

If $u \in P2$ then

$$G_X(X) = (x_o - PC(u), x_1, \ldots x_s) \quad \text{if } PC(u) \leqslant x_o$$

$$= \emptyset \quad \text{otherwise.} \quad (2.13)$$

'$\emptyset$' is a null vector.

Using equations 2.7 to 2.13, a dynamic computational procedure can be set up.

Both the formulations discussed above have been computerized. Their computational aspects are discussed in following chapter.

2.5 DATA FOR THE ANALYSIS

Principal data required for the analysis are :

1. Equipment requirement.
2. Materials handling cost.
3. Permissible Location Combinations.

To obtain these, following data have to be compiled from the various sources (from the existing plant, handling equipment suppliers etc.).

2.5.1 Data Compilation

1. LOCATION MATRIX (L)

This matrix gives the alternate locations for the new facilities. There is a possibility that due to some technological reasons a particular machine can not be located at some locations. The element of this matrix are either 0 or 1.

$L(I, J) = 0$ If Ith new machine can not be located at location J.

$= 1$ If Ith new machine can be located at location J.

From this matrix possible location combinations can be generated.

2. DISTANCE MATRIX (D)

This matrix can be developed by the layout drawing of the plant. The physical distance between any two layout points can be measured, depending upon the conditions imposed by the material handling system used and the present layout. Distance matrix is developed for two basic types of handling equipment movement namely straight line movement case and rectangular movement case.

If N = Number of potential locations

M = Number of existing machines.

Then

$D(I, J, K)$ = Distance between the location pair I-J (or existing machine if $J > N$) for Kth type of movement case.

K = 1 Rectangular movement case.

K = 2 Straight line movement case.

3. MATERIALS HANDLING EQUIPMENT SPECIFICATIONS

The specifications of the various materials handling equipment can be sought from the suppliers. These specifications include the capacity, the purchase cost etc. The operating cost for the equipment has to be calculated, based on costs of fuel, routine maintenance, repairs, maintenance overheads and depreciation of the equipment.

4. MATERIALS HANDLING VOLUME (MHV)

The basic method to define the materials handling volume between two facilities is from-to chart or matrix. This matrix shows the inter-facility materials flow in unit loads per unit time for a particular handling system.

MHV (I, J, K) = Materials flow between I - J machine pair for Kth handling system.

5. MATERIALS HANDLING ALTERNATIVES (MHA)

Depending upon the type of materials flow, this matrix gives the alternate materials handling equipments that can be used for transporting materials between a machine pair. This matrix is coded in three numbers viz., 0, 1 or 2. This implies that :

MHA (I, J, K) = 2 If there is no flow of material between machine pair I - J.

= 1 If equipment K can be used for transporting material between machine pair I - J.

= 0 If equipment K can not be used for machine pair I - J.

6. STANDARD TIME PER MOVE

Standard operation time can be calculated by studying the basic operations during a move e.g., for a fork truck, these operations are :

a. At start :

Lower fork empty

Raise fork loaded

b. Run

c. At the end of run :

Raise fork loaded

Lower fork empty.

Time for these moves can either be calculated by time study or by using standard graphs usually supplied by the manufacturers of the equipment.

To this operation time, must be added contingency factors time which include time lost if some restriction by other loads or obstruction reduces the running speed. This time depends upon the operating conditions in the plant. Thus :

$$\left\{ \begin{matrix} \text{Normal Time} \\ \text{per move} \end{matrix} \right\} = \left\{ \text{Run time} \right\} + \left\{ \begin{matrix} \text{Lower and} \\ \text{Lift time} \end{matrix} \right\} + \left\{ \begin{matrix} \text{Contingency} \\ \text{factors time} \end{matrix} \right\} \quad (2.14)$$

To arrive at the standard time, allowances for personal time, fatigue and unavoidable delays are added to normal time.

$$\left\{ \begin{matrix} \text{Standard Time} \\ \text{Per move} \end{matrix} \right\} = \left\{ \begin{matrix} \text{Normal Time} \\ \text{Per move} \end{matrix} \right\} + \left\{ \text{Allowances} \right\} \quad (2.15)$$

2.5.2 Data Analysis

From the data of the previous section, equipment requirement and materials handling cost can now be calculated.

1. ESTIMATING EQUIPMENT REQUIREMENTS

Based upon the standard time and material handling volume from from-to chart, a deterministic estimate for materials handling equipment requirement for a particular flow path can be made by using the following formula :

$$\text{AMHR}(I, J, K) = \frac{\text{MHV}(I, J, K) * \text{ST}(I, J, K)}{H * K * 60} \quad (2.16)$$

Where AMHR (I, J, K) = Number of Kth type of equipment required along flow path I - J.

MHV (I, J, K) = Material flow per month in unit load per unit time for Kth handling system.

ST (I, J, K) = Standard time in minutes, per move for Kth equipment between machine pair I-J.

H = Standard hours per month.

K = Utilization factor of Kth equipment.

2. MATERIALS-HANDLING COST

Materials handling cost for transporting material between a machine pair for a particular handling system is

$$C(I, J, K) = D(I, J, K) * OC(K) * MHV(I, J, K) \qquad (2.17)$$

Where $C(I, J, K)$ = Materials handling cost for transporting material between machine pair I - J with Kth handling system.

$OC(K)$ = Operating cost for Kth type of handling system.

CHAPTER III

COMPUTATIONAL ASPECTS

In the previous chapter two alternate formulations were proposed, solving them by conventional methods on computer will require lot of computation time and unmanageable high speed memory locations. In this chapter computational aspects of the two approaches are discussed. Section 3.1 deals with modifications in zero-one programming procedure to save computation time where as in Section 3.2 a method to overcome dimensionality problem in the dynamic programming approach has been suggested.

3.1 MODIFICATION IN ZERO-ONE PROGRAM

3.1.1 Solving Procedure For General Zero-One Program

At present several methods are available for solving linear programs of the 0 - 1 type. Best known among them are R.E. GOMORY'S [11] algorithm for solving linear programs with integer variables. He uses the dual simplex method and imposes the integer conditions by adding automatically generated new constraints to the original constraint set.

Another algorithm for integer linear programs, developed by A.H. LAND and A.G. DOIG [12], starts with a non-integer optimal solution and then finds the optimal integer solution through parallel shift of the objective function - hyper plane.

All the above algorithms require solution of corresponding ordinary linear program (without the zero-one constraint) for each iteration and therefore, are affected by round off errors. Moreover, these algorithms do not take full advantage of the 0 - 1 property of the variables. IVANESCU [13] has suggested a different approach based on Boolean algebra concepts. Another approach has been developed by BALAS [14] . Both these methods attack directly the 0 - 1 program and there is no round off errors as operations consist of only additions and subtractions.

Many more procedures have been developed and reported in literature to handle particular type of 0 - 1 programs. However, for the present work Balas' algorithm is used because of its generalized nature and it works quite efficiently for the type of problems in which most of the variables take '0' values [14] . For this study package program for modified Balas algorithm given by MIZE and KUESTER [15] is used.

3.1.2 Modifications For Present Work

The problem in its generalized form can be stated as :

$$A_K \; X \; \begin{matrix} \leq \\ = \\ \geq \end{matrix} \; b_K \qquad (3.1)$$

$$\text{Min} \quad Z_K = C_K \, X \qquad K = 1, \text{IC}$$

with an overall objective function

$$\underset{K}{\text{Min}} \quad (Z_K) \qquad (3.2)$$

Where IC = Number of location combinations.

The most obvious procedure is to solve each program using Balas algorithm and select the combination with lowest value of Z_K. But computationally this is not economical because of the large computation time required to solve a 0 - 1 program.

Another procedure is to couple all the (LC) programs to a single 0 - 1 program. However, not much saving in the computation time was achieved and even in some cases the time required was more than the total time required for solving the problems individually.

Coming back to the generalized case, the problem can be physically presented for the two variable case as shown in Figure 3.1.

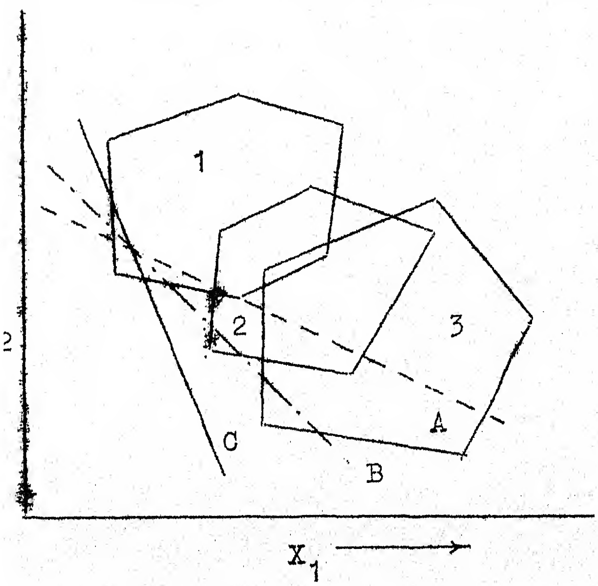

FIGURE - 3.1 GRAPHICAL REPRESENTATION OF ZERO-ONE PROGRAMMING FORMULATION.

1, 2, 3 are the convex feasible regions corresponding to different location combinations. Exploration of each feasible region involves the solving of a seperate problem. When problem 1 is solved, a minimum value, Z_{min}, of the objective function is achieved. Before solving problem 2, an additional constraint

$$C_2 X \leq Z_{min} \tag{3.3}$$

is introduced. Depending upon the vector C_2, the constraint can take either direction A or B or C. Cases A and B show that modified problem - 2 has a feasible solution without 0 - 1 constraint. In case A, 0 - 1 feasible solution is

present whereas in Case B there is no feasible 0 - 1 solution. In case C, there is no feasible solution. Lot of computation time can be saved if it can be found before hand, whether the present location combination is going to improve the objective value or not. Case C can be detected by coupling a revised simplex program with Balas algorithm package and using phase I to find the feasibility of the problem. The general solution procedure can now be summarized in the following steps.

1. Let Z_{MIN} (I) = Minimum value of objective function before Ith location combination is tested.

2. Add the constraint $C_I X \leqslant Z_{MIN}$ (I) in the Ith problem set and find using phase I of revised simplex procedure, whether feasible solution exists or not.

3. If no feasible solution is present, then, $Z_{MIN}(I + 1) = Z_{MIN}(I)$. Take the next problem set and repeat the procedure.

4. If feasible solution exists, use Balas algorithm for finding 0 - 1 integer solution of the problem giving value of objective function as Z_I. Z_I will be a high number if there is no feasible 0 - 1 solution.

5. Put $Z_{MIN}(I + 1) = \text{Min}\left\{Z_I, Z_{MIN}(I)\right\}$. Repeat the procedure with next location combination.

A logic flow diagram for the above procedure is given in Appendix - 1.

3.2 DIMENSIONALITY PROBLEM IN DYNAMIC PROGRAMMING APPROACH

Solving the dynamic programming formulation of the location problem using conventional dynamic programming computational procedure proposed by RICHARD BELLMAN [16] is impossible because of the enormous computation time required and due to what Bellman [16] calls "the curse of dimensionality" - i.e., the excessively high speed memory locations required. For a problem consisting of two handling-systems, 5 location combinations and a state increment of .1, the memory requirement is of the order of 200 K which is beyond the capacity of many present day commercially available digital computers. ROBERT E. LARSON [17] has proposed a state increment dynamic procedure to overcome the dimensionality problem. The technique consists of doing computation in small blocks, but it is assumed that the next state after a control action is taken, always lies in the neighbourhood of present state. For the present work this assumption is not valid. Therefore, a variable state procedure is proposed.* This new procedure has computational requirements that are significantly less than those for the conventional case. In particular, the high speed memory requirement is always reduced, generally by orders of magnitude.

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*This procedure is named variable state dynamic procedure, because the effective states in this procedure are blocks instead of grid points and these blocks vary at each stage.

3.2.1 VARIABLE STATE DYNAMIC PROGRAMMING

Philosophy behind the variable state dynamic procedure is that for a problem in which there are few stages and discrete decision variables, many neighbouring states have the same optimal solution. So instead of storing control action and objective value at each grid point of a multidimensional state field, only the blocks having the same optimal solution and corresponding control action and objective value can be stored. The memory requirement can therefore be reduced drastically. Computation time can also be reduced by using the fact that if the diagonal points of a block, one nearest and another farthest to the origin (Ø state), have the same optimal solution, then every grid point with in the block has the same optimal solution as the diagonal points. Hence, by using proper search procedure, solution at many grid points can be found implicitly without actual computation.

For the present work, conventional dynamic programming procedure is used for states in Y direction, whereas variable state dynamic procedure is applied for states in X direction. The variable state procedure is summarized in the following steps :

STEP : 1

Discretize the states X (J) with increment ΔX_J . As explained in section 2.3, X (J) is a (S + 1) dimensional vector and hence the discretized values of X will form a (S + 1) dimensional grid. These discretized values of X are the points where computations

are to be made. The grid points are identified by using coordinate system with state (0, 0, ... 0) as the origin. State X (J) can be represented as X (J) = $\{\beta_J\}\{\Delta X_J\}$. Then the coordinates of X (J) are (β_J).

STEP : 2

Create a master list which stores the coordinates of diagonal points of candidate blocks. Initially at each stage this will contain a block having all the grid points within it. A block is identified by its two diagonal points, one nearest to and another farthest from the origin. The coordinates of the two diagonal points are a (J), J = 1, 2, ... (S + 1) and C (J), J = 1, 2, ... S + 1 respectively.

STEP : 3

If master list is empty - go to step 13.

STEP : 4

Take out first candidate block from the master list and put X (J) = a (J) where J = 1, 2, ... S + 1. Find optimal solution ISOL at this point, using recursive relations of section 2.3

STEP : 5

Put X (J) = X (J) + n ΔX_J; for all J. Where $n = 2^K$ (K is any integer).

STEP : 6

If all X (J) < C (J), go to step 7 otherwise go to step 8.

STEP : 7

Find optimal solution at point X (J). If solution is same as ISOL, go to step 5. Otherwise go to step 8.

STEP : 8

If n equal to 1, go to step 9. Otherwise put $n = n/2$ and start the search procedure from step 5 with the previous grid point.

STEP : 9

Increment, individual X (J)'s, as far from the origin as possible, such that optimum solution is the same as ISOL.

Diagonal points a (J)'s and X (J)'s give a block, having the same optimal solution ISOL.

STEP : 10

Remove the block from the main block and divide remaining space in proper candidate blocks. A partitioning procedure for different position of solution block in three-dimensional grid is shown in Fig. 3.2.

STEP : 11

Enter the partitioned blocks in master list.

STEP : 12

Go to step 3.

STEP : 13

Search procedure is completed, proceed to next dynamic programming stage.

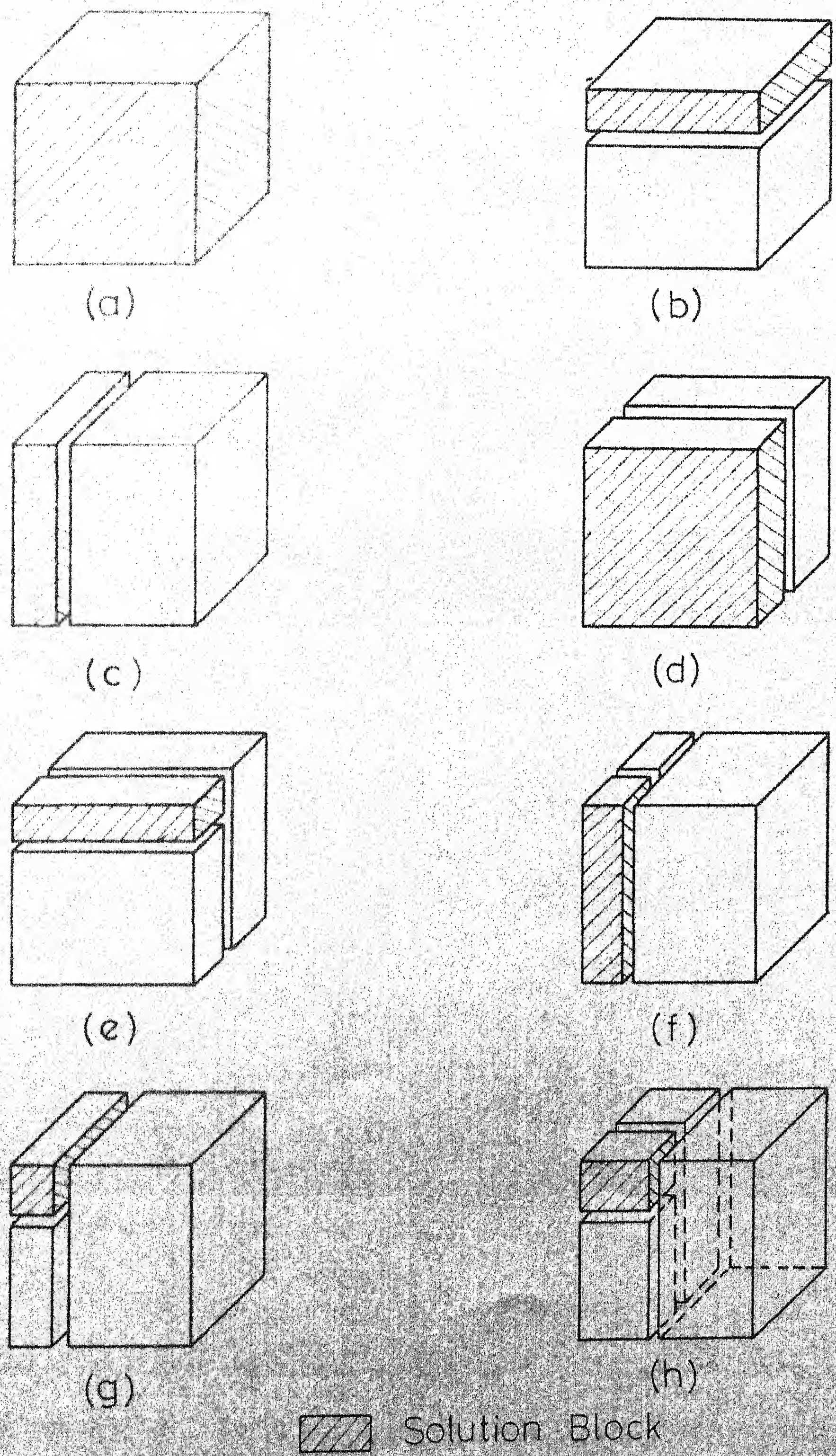

FIGURE-3-2 PARTITIONING OF BLOCK

The solution procedure is further illustrated in figures 3.3 to 3.5 by solving a small location problem with two stages (flow paths) and one location combination. A case is considered where a new machine is to be added to a plant. This would introduce two new flow paths into the system. For each flow path, either a handling truck (Decision - 1) or a conveyor can be used for materials handling. Using dynamic programming procedure, handling equipment for each flow path has to be selected. Data for the problem are :

Flow Path - 1

Decision Variable	1	2
Equipment Requirement	.7	1
Handling Cost	Rs. 500	Rs. 400
Purchase Cost of handling equipment	Rs. 13,000	Rs. 19,000

Flow Path - 2

Decision Variable	1	2
Equipment Requirement	.6	1
Handling Cost	Rs. 595	Rs. 500
Purchase cost of handling equipment	Rs. 13,000	Rs. 22,000

Maximum finance available = 30,000.

In this case S = 1, hence discretized states form a two dimensional grid as shown in Figure 3.3. Increment in direction - 1 (representing finance available) is Rs. 1,000 where as along direction-2

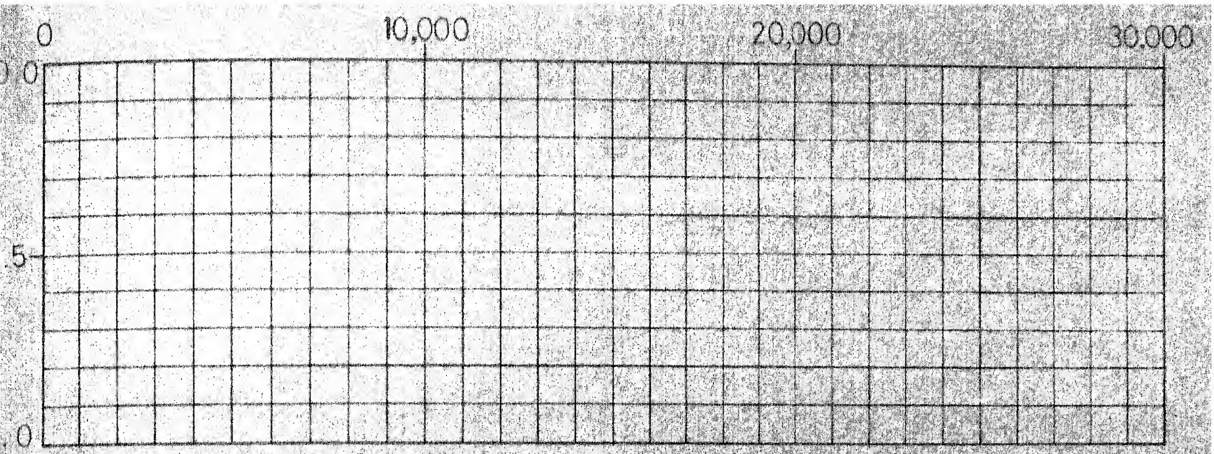

FIGURE - 3 - 3 TWO DIMENSIONAL GRID

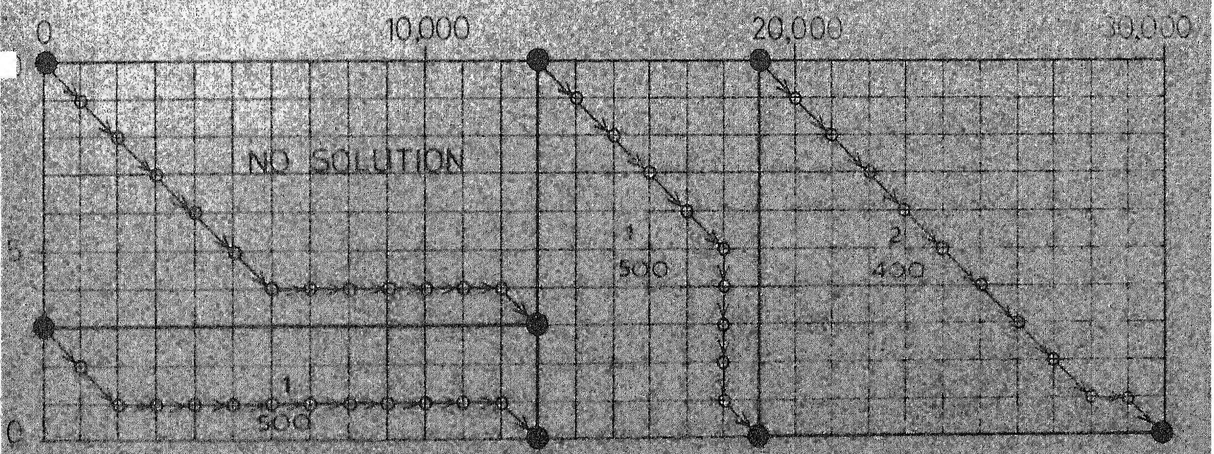

FIGURE - 3 - 4 STAGE - 1 OF DYNAMIC PROGRAMMING

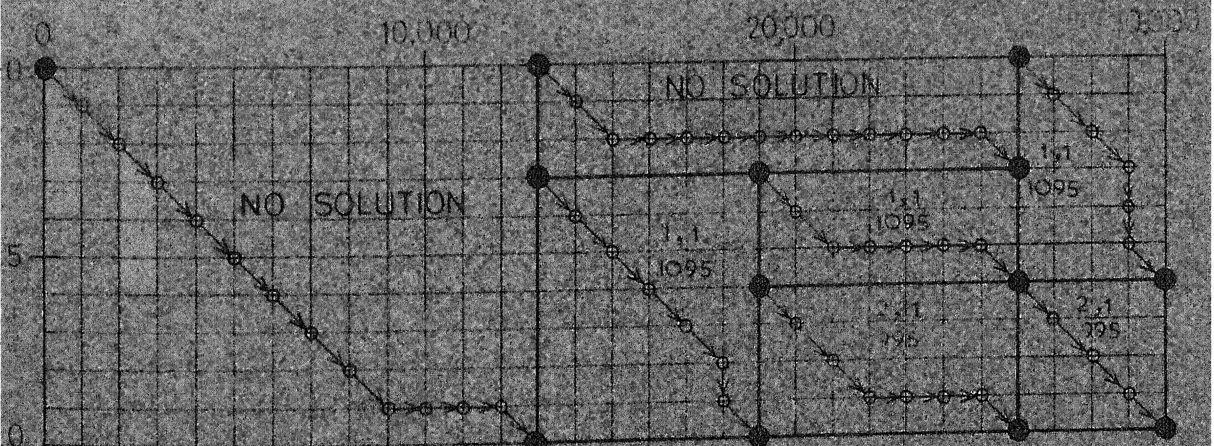

FIGURE - 3 - 5 STAGE - 2 OF DYNAMIC PROGRAMMING

(representing fraction of truck available), it is .1. Using the search procedure explained earlier and the recursive relations of section 2.3, the state field is divided into number of blocks having the same solution. Figure 3.4 illustrates search procedure for stage - 1 where as stage - 2 is explained in Figure 3.5. Numbers within the block are the optimal control action for the two flow paths. The first number corresponds to the first flow path while the second number corresponds to the second flow path. The symbols ✱ and • represent grid points where computation is performed, and the diagonal points of the blocks having the same solution respectively. For this example the optimal solution occurs at point (30,000,0), i.e., use truck for both flow paths.

It is interesting to note that if conventional dynamic programming would have been used, then control actions and objective values at a total of 600 states will have to be stored where as using variable state dynamic procedure this number is as low as 22. Moreover computation is performed at only around 100 grid points as compared to 600 in conventional dynamic programming procedure.

A computer program for this procedure has been written in FORTRAN - IV. A general logic flow diagram for the program is given in Appendix - 2.

CHAPTER IV

RESULTS AND DISCUSSION

In all, eight randomly generated problems of various sizes are solved using both the procedures. For problem - 1 data concerning acceptable locations of new machines, distances between two machines, material flow between a machine pair and the alternate handling equipment used, are borrowed from WILLIBOUGH'S paper [10]; handling equipment specifications are taken from catalogues obtained from M/s McNally Bird Ltd and the standard times per move of various handling systems between a machine - pair are generated using random number tables. For this problem sensitivity analysis is performed for each parameter. Other problems of varied sizes are solved to estimate the computational efficiency and limitations of the two procedures.

4.1 TEST PROBLEM - 1

4.1.1 Problem Statement

It is desired to locate three new facilities on a plant floor. Four existing facilities are already in operation in the plant and their materials handling loading and unloading stations are designated as F_I, F_{II}, F_{III} and F_{IV} as shown in Figure 4.1.

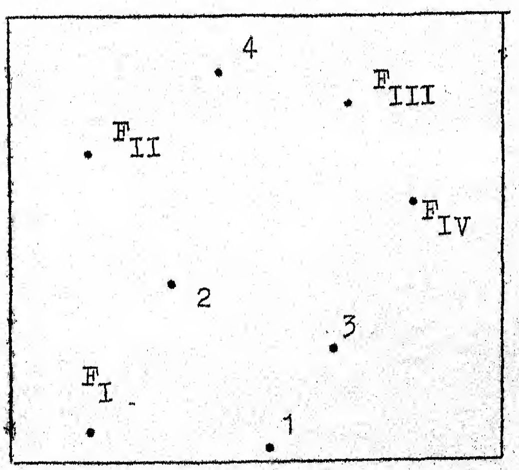

FIGURE 4.1 : LOCATIONS OF EXISTING MACHINES AND AVAILABLE AREAS.

There are four locations on the plant floor which may accommodate

one or more of the facilities. These locations are designated by Arabic Numerals in Figure - 4.1. The other data are as follows :

4.1.2 Input Data

(a) Acceptable Locations :

Facilities to be located are limited to the available locations as shown in Table 4.1.

TABLE 4.1

ACCEPTABLE LOCATIONS FOR THE NEW FACILITIES - PROBLEM - 1

NEW MACHINE	LOCATION NUMBER 1	2	3	4
A	1	1	1	1
B	1	0	1	0
C	0	1	1	0

'1' at (A, L1) denotes that A can be located at L1 where as '0' at (B, L2) shows that B can not be located at L2.

(b) Distance Matrix

Equivalent distance between existing facilities and new locations for type of movement followed by handling equipment is given in Table 4.2.

TABLE 4.2

DISTANCE BETWEEN LOCATIONS - PROBLEM - 1

LOCATION PAIR	DISTANCE IN METERS	
	RECTANGULAR MOVEMENT CASE	STRAIGHT LINE MOVEMENT CASE
1 - 2	20	15
- 3	18	10
- 4	32	23
2 - 3	18	13
- 4	13	12
3 - 4	32	20
FI - 1	17	13
- 2	20	12
- 3	25	17
- 4	32	22
FII - 1	32	20
- 2	13	8
- 3	32	20
- 4	18	10
FIII - 1	35	25
- 2	25	17
- 3	22	15
- 4	20	15
FIV - 1	35	25
- 2	23	22
- 3	22	10
- 4	35	25

(c) Handling Equipment Specifications

Specifications of alternate material handling systems are summarized in Table 4.3.

TABLE 4.3

SPECIFICATIONS OF MATERIALS HANDLING SYSTEMS PROBLEM - 1

SYSTEM	SYSTEM CODE	CAPACITY	PURCHASE COST	OPERATING COST	AVG. SPEED
Hi-Stack* (Electric Fork-lift Truck)	P	2 Tons	Rs. 60,000	Rs. 1.05/Mt	6 Km/hr
Mazdur-1015* (Hand-Truck)	Q	1 Ton	Rs. 5,000	Rs. .60/Mt	2 Km/hr
Belt Conveyor	S	-	Rs. 800/Mt.	Rs. .45/Ton/Mt	-
Trolley Conveyor	T	-	Rs. 1,200/Mt.	Rs. .55/Ton/Mt	-

*Trade names of Trucks manufactured by McNally Bärd & Co.

(d) Standard Time Per Move :

In Table 4.4 for each location pair the standard time per move for two types of trucks under consideration are given.

TABLE 4.4

STANDARD TIME PER MOVE - PROBLEM - 1

LOCATION PAIR	TIME IN MINUTES	
	ELECTRIC FORK TRUCK	HAND TRUCK
1 - 2	12	18
- 3	12	15
- 4	19	28
2 - 3	12	15
- 4	10	13
3 - 4	19	28
FI - 1	12	15
- 2	13	18
- 3	14	20
- 4	19	28
FII - 1	19	28
- 2	10	13
- 3	19	28
- 4	12	15
FIII - 1	21	29
- 2	14	20
- 3	14	20
- 4	12	18
FIV - 1	21	29
- 2	14	20
- 3	14	20
- 4	21	29

(e) Material Handling Alternatives

The alternate handling systems which can be used for particular flow path are listed in Table 4.5. (P, Q, S) at (A, B) shows that for flow path A - B any of handling equipment P, Q or S can be used for transporting material where as 'X' at A - C represents no flow of material between the machine pair.

TABLE 4.5

ALTERNATE MATERIAL HANDLING SYSTEMS - PROBLEM - 1

	A	B	C	FI	FII	FIII	FIV
A	...	P,Q,S	X	X	P,Q	X	P,Q
B	...	...	Q,T	P,Q	P,Q,T	P,T	X
C	...	...	...	P,S	X	X	P,Q,S

(f) Monthly Unit Load

Table 4.6 gives the monthly material flow in unit load of handling equipment for a machine pair.

TABLE - 4.6

MONTHLY MATERIAL FLOW IN UNIT LOADS PER MONTH

HANDLING EQUIPMENT	FLOW PATH A-B	A-FII	A-FIV	B-C	B-FI	B-FII	B-FIII	C-FI	C-FIV
P	100	200	125	x	125	75	225	50	25
Q	200	400	250	300	250	150	x	x	50
S	200	x	x	x	x	x	x	100	50
T	x	x	x	300	x	150	450	x	x

Finally due to capital restrictions no more than Rs. 1,20,000 can be invested for the purchase of material handling equipment.

4.1.3 Result

The above mentioned problem is solved by using 0 - 1 programming procedure and final results are tabulated in Table 4.7. The value of the equipment utilization factor is assumed to be 0.7. The computation time required was of the order of 30 Min. on IBM 7044/1401 computer.

TABLE 4.7

OVERALL OPTIMUM FACILITY LOCATION - HANDLING SYSTEM SELECTION POLICY - PROBLEM - 1

FACILITY	ASSIGNED LOCATION	FLOW PATH	SYSTEM SELECTED	MONTHLY HANDLING COST-Rs.	CAPITAL COST Rs.
A	L2	A-FII	Q	3,120	5,000
		A-FIV	Q	3,450	5,000
B	L1	B-A	S	1,350	12,000
		B-FI	Q	2,550	-
		B-FII	T	1,640	24,000
		B-FIII	T	6,200	30,000
C	L3	C-B	T	1,650	12,000
		C-FIV	S	225	8,000
		C-FI	S	765	13,600
			Total	Rs. 20,950	Rs. 1,09,600

In Table 4.7, corresponding to the flow path B-FI no investment has been indicated. This is due to the fact that it can share the trucks purchased for flow path A-FII and A-FIV.

4.1.4 Sensitivity Analysis

Sensitivity analysis has been performed for the following parameters :

1. Handling equipment utilization factor.
2. Cost parameters.
3. Constraint on investment.

(a) Handling Equipment Utilization Factor

For determining the equipment requirements for each flow path a utilization factor K is introduced to take into account the break-downs and other unavoidable delays. Generally, for design purposes the value of K is taken equal to .7. However, an analysis is performed here for various values of K to determine the response of optimal solution to changes in utilization factor of the handling equipment. Table 4.8 gives the solution for various values of K.

TABLE 4.8

OVERALL OPTIMUM FACILITY LOCATION - HANDLING SYSTEM SELECTION POLICY WITH K AS A PARAMETER - PROBLEM - 1

K	ASSIGNED LOCATION A	B	C	SYSTEM SELECTED A-FII	A-FIV	B-A	B-FI	B-FII	B-FIII	C-B	C-FIV	C-FI	MATERIAL HANDLING COST Rs.
.6	L2	L1	L3	Q	Q	S	Q	T	T	T	S	S	20,950
.7	L2	L1	L3	Q	Q	S	Q	T	T	T	S	S	20,950
.8	L2	L1	L3	Q	Q	S	Q	T	T	T	S	S	20,950

Results show that with the present set of data even if the performance of handling equipments deteriorates to .6 or improves to .8, the optimum solution is not affected.

(b) Cost Parameters

Handling cost is quite nebulous in character because it involves human judgement and error. Therefore, a sensitivity analysis on handling cost to study its influence on the various decisions is very desirable. The optimal solution obtained on varying each cost parameter independently by 10% on either side are given in Table - 4.9.

TABLE 4.9

OVERALL OPTIMUM FACILITY LOCATION - HANDLING SYSTEM SELECTION POLICY WITH OPERATING COSTS AS PARAMETER - PROBLEM - 1

		Normal cost Parameters	Variation in Cost Parameters							
			CP		CQ		CS		CT	
			+ 10%	-10%	+ 10%	-10%	+10%	- 10%	+10%	-10%
ASSIGNED LOCATION	A	L2	L2	L2	L2	L2	L2	L2	L2	L2
	B	L1	L1	L1	L1	L1	L1	L1	L1	L1
	C	L3	L3	L3	L3	L3	L3	L3	L3	L3
FLOW PATH	A-FI	Q	Q	Q	Q	Q	Q	Q	Q	Q
	A-FIV	Q	Q	Q	Q	Q	Q	Q	Q	Q
	B-A	S	S	S	S	S	S	S	S	S
	B-FI	Q	Q	Q	Q	Q	Q	Q	Q	Q
	B-FII	T	T	T	T	T	T	T	T	T
	B-FIII	T	T	T	T	T	T	T	T	T
	C-B	T	T	T	T	T	T	T	T	T
	C-FIV	S	S	S	S	S	S	S	S	S
	C-FI	S	S	S	S	S	S	S	S	S
MATERIAL HANDLING COST IN Rs.		20950	20950	20950	21863	20037	21185	20715	21899	20001

Results given in Table 4,9 show that the optimal solution does not change with the 10% variation in cost component i.e. even if operating costs are calculated wrongly, the optimal solution is not influenced atleast for error upto 10%.

(c) Investment Constraint

Although investment is a management decision, yet it is desirable to study the effect of this parameter on overall optimal solution. If there is a significant saving by little extra investment, this alternative can always be recommended for management's consideration. For the present problem optimal solution is obtained for various levels of investment. The results are summarized in Table 4.10.

TABLE 4.10

OVERALL OPTIMUM FACILITY LOCATION - HANDLING SYSTEM SELECTION POLICY WITH INVESTMENT AS PARAMETER - PROBLEM - 1

Investment Rs.	Assigned Locations			System Selected									Material Handling Cost Rs.
	A	B	C	A-FII	A-FIV	B-A	B-FI	B-FII	B-FIII	C-B	C-FIV	C-FI	
1,10,000	L2	L1	L3	Q	Q	S	Q	T	T	T	S	S	20,950
1,20,000	L2	L1	L3	Q	Q	S	Q	T	T	T	S	S	20,950
1,40,000	L2	L1	L3	P	P	S	P	T	T	T	P	P	20,694
1,50,000	L2	L1	L3	P	P	S	P	T	T	T	S	P	20,347
1,60,000	L2	L1	L3	P	P	S	P	T	T	T	S	S	19,800

Table 4.10 shows that with the increase in investment level, monthly materials handling cost reduces. It is for management to decide whether the saving is worth the extra investment or not.

4.2 ZERO-ONE PROGRAMMING Vs. DYNAMIC PROGRAMMING PROCEDURE

Attempt was also made to solve Problem - 1 by dynamic programming procedure but it failed because of high memory requirement. Therefore, to assess the applicability and efficiency of this procedure, problems of varying size were solved. Details of these problems are given in Appendix - 3. Appendix - 4 gives a sample output of dynamic programming procedure.

The respective time required by both procedures for various problems are listed in Table 4.11. As expected, time required by dynamic programming procedure is significantly more than that required by Zero-one programming approach. However, much more information obtained by dynamic procedure outweighs the extra time required. In a single computation run, dynamic programming procedure gives optimum handling system selection policy for each location combination and for different levels of investment where as zero-one programming procedure gives only the overall optimum policy for a particular investment level.

The extra information obtained in dynamic programming procedure is very useful. They avoid the extra computation run needed for step - 3 of sensitivity analysis. Moreover, solutions for all location combinations give a chance to consider unaccountable supplementary layout criterion for the cases when solution at few location combinations are not significantly different from the over all optimal solution.

If one tries to obtain all the information which gets automatically generated by the dynamic programming procedure, using zero-one programming, the computation time required would have been much more than the corresponding time for dynamic programming procedure.

TABLE 4.11

ZERO - ONE PROGRAMMING PROCEDURE Y/S DYNAMIC PROGRAMMING APPROACH

Problem No.	No. of New Machines	No. of Locations	No. of Flow Paths	Computation Time on IBM 7044/1401: 0-1 Programming Procedure	Computation Time on IBM 7044/1401: Dynamic Programming Procedure
1	3	4	9	31 Min.	Can not be solved because of large memory locations reqd.
2	1	2	2	6 Sec.	10 Sec.
3	2	3	3	8 Sec.	14 Sec.
4	2	3	4	1 Min. 11 Sec.	2 Min. 40 Sec.
5	2	3	5	1 Min. 1 Sec.	2 Min. 10 Sec.
6	2	3	6	2 Min. 41 Sec.	6 Min. 46 Sec.
7	2	4	5	2 Min. 15 Sec.	7 Min. 28 Sec.
8	3	5	7	-	Can not be solved because of large memory locations reqd.

4.3 LIMITATIONS OF PROPOSED APPROACHES

Both zero-one programming and dynamic programming procedures give optimal solution to joint Facility Location - Handling System selection problem. Nevertheless, there are limitations to these models. The models are limited to deterministic flow data. If flow data can be taken with a high degree of confidence, then the procedures should work well. However, in practical situations it is more likely that flow data will be stochastic and subject to random variations. Further study is needed to determine the sensitivity of the layout solution to flow variations.

Another limitation occurs due to the size of problem that can be handled. Large memory requirements have restricted the application of dynamic programming procedure to only upto 6 flow paths. Problems up to 3 new machines, 9 flow paths have been solved using 0 - 1 programming approach in less than 30 Minutes on IBM 7044/1401 system, but computation time required increases exponentially with the increase in the size of problem.

4.4 CONCLUSION

Inspite of the above mentioned limitations, the models promise to be useful tools in analyzing small size layout problems. Many layout modification problems require addition of 3 to 4 new machines which introduces less than 10 new flow paths. For such cases dynamic programming (problems up to 6 flow paths)

or zero-one programming procedure (new flow paths more than 6) can very well be used. However for larger problems, still better approach needs to be developed.

4.4 SUGGESTIONS FOR FURTHER WORK

A few suggestions for the extension of the present work are listed below :

1. In all the above reported literature, including present work, the objective was to minimize the materials handling cost and no weightage was given to the corresponding investment. Therefore a better objective function could have been one, which simultaneously considers both investment as well as materials handling cost. One of the approaches may be to minimize the present worth of investment and materials handling cost over a predefined design period. This will slightly modity the objective function in case of zero-one programming procedure but to take into account this aspect in dynamic programming formulation can be a challenging problem.

2. In both the formulations wages of handling equipment operators were not considered. In case of dynamic programming procedure it is not possible to take this into account, but for zero-one programming approach the objective function can be modified as follows :

If

$W(J)$ = Wage of operator of Jth type of handling equipment

then

$$Z_K = \sum_{J \in P} \sum_{I=1}^{F} C(I,J,K) \cdot X(I,J,K) + \sum_{J \in P1} W(J) * Y(J,K)$$

Same procedure can now be used to solve this problem.

3. In case of dynamic programming procedure, major fraction of the computer time for finding solution at a grid point is taken in finding corresponding block in the previous stage for state after transformation. Much of the computer time can be saved if an efficient method to search block for corresponding state can be devised.

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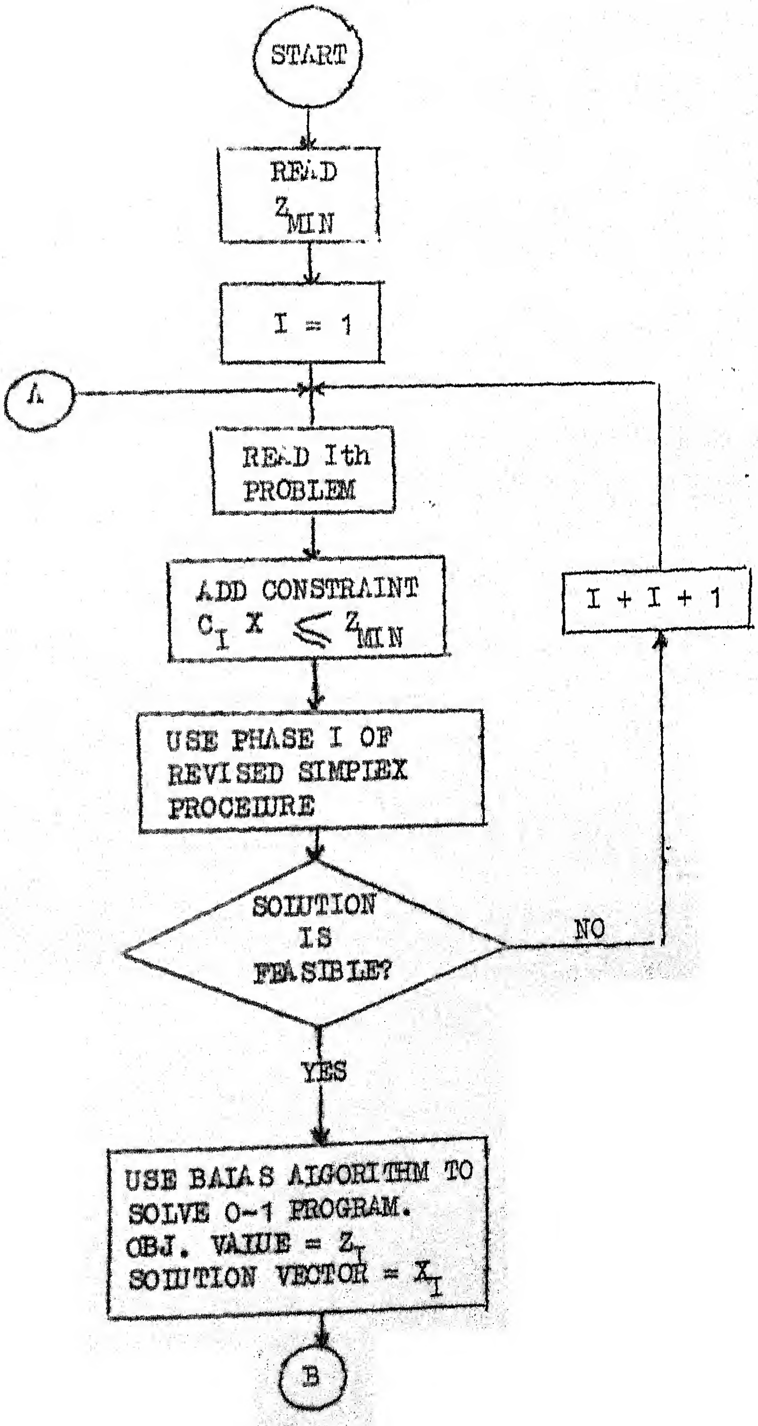
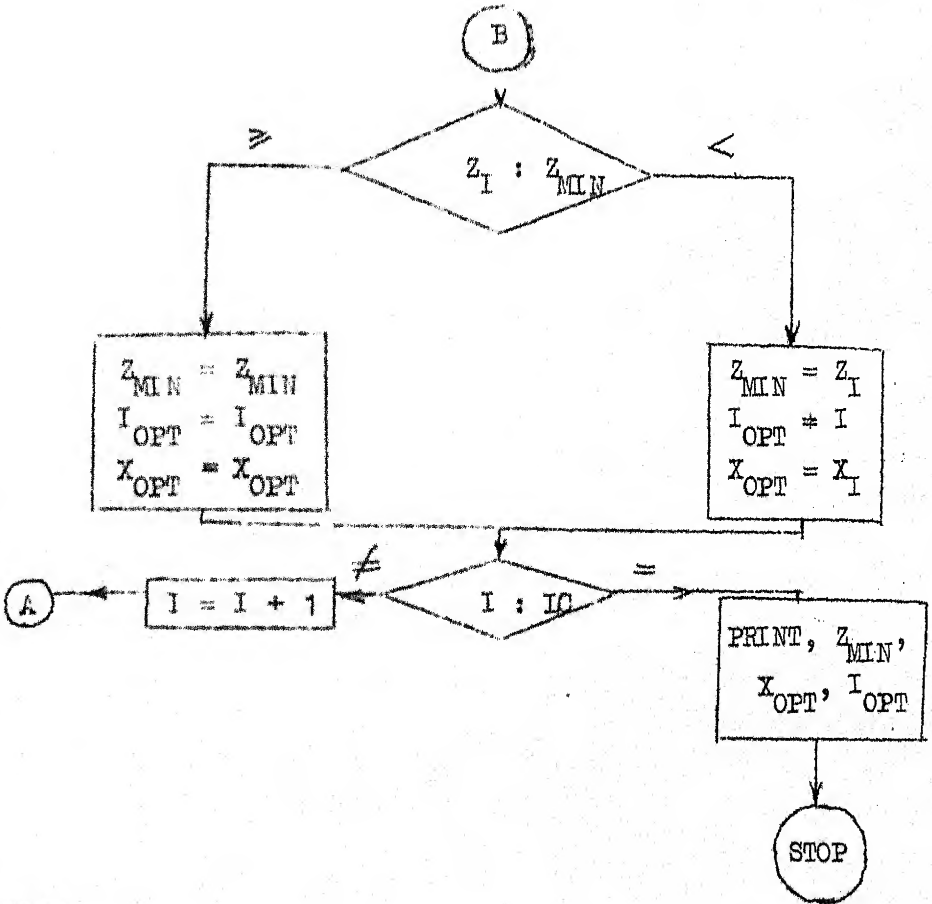
APPENDIX - I

LOGIC FLOW DIAGRAM FOR ZERO-ONE PROGRAMMING PROCEDURE





LEGEND

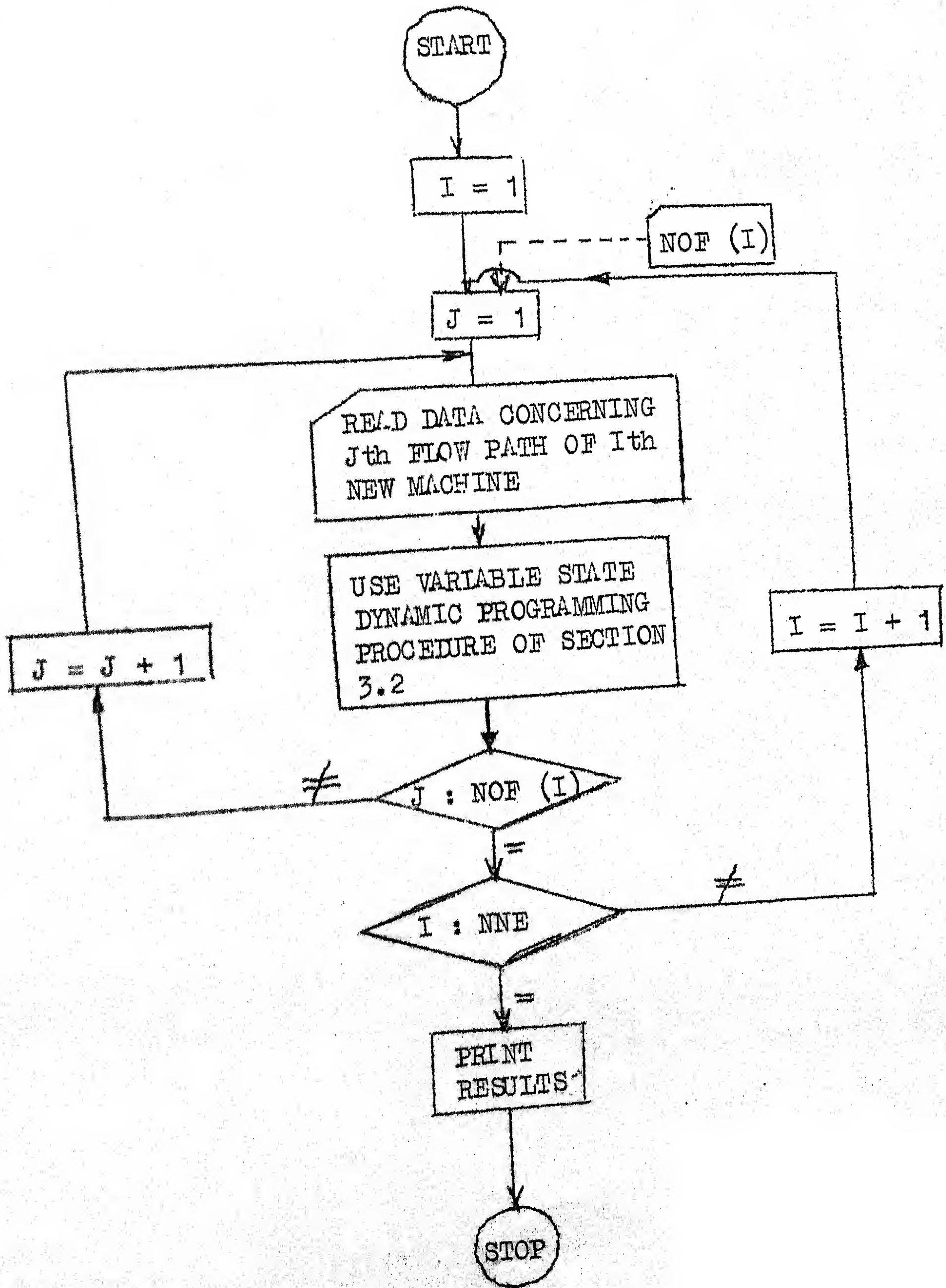
I_{OPT} : Optimal location combination.

X_{OPT} : Optimal Solution Vector for equipment selection.

IC : Number of Location Combinations.

APPENDIX II

LOGIC FLOW DIAGRAM FOR DYNAMIC PROGRAMMING PROCEDURE



LEGEND

NOF (I) = Number of Flow Paths for Ith new machine.

NNE = Number of new machines.

APPENDIX - 3

Data for the various problems are given below :*

PROBLEM - 2

(A) ACCEPTABLE LOCATIONS

NEW MACHINE	LOCATION	1	2
A		1	1

(B) ALTERNATE MATERIALS HANDLING SYSTEMS

NEW MACHINE	EXISTING MACHINE	FI	FII
A		P,Q	P,Q,T

(C) OTHER DATA

	LOCATION	HANDLING	SYSTEM		
	A	P	Q	S	T
FLOW PATH A-FI					
Equipment Requirement	1	.18	.45	-	-
	2	.21	.60	-	-
Materials handling cost in Rs./Month	1	2,227	2,550	-	-
	2	3,275	3,750	-	-
Equipment Requirement	1	.18	.51	-	1.0
	2	.18	.51	-	1.0
Materials handling cost in Rs./Month	1	2,518	2,880	-	1640
	2	2,518	2,880	-	1640
Purchase cost of handling equipment	1	-	-	-	24,000
	2	-	-	-	24,000

PROBLEM - 3 and 4

(A) ACCEPTABLE LOCATIONS :

NEW MACHINE	LOCATION	1	2	3
A		1	1	1
B		1	0	1

(B) ALTERNATE MATERIALS HANDLING SYSTEMS

	A	B	FI	FII
A	-	P,Q,S	-	P,Q,S
B	-	-	P,Q	P,Q,T

(C) OTHER DATA

	LOCATION		HANDLING SYSTEM			
	A	B	P	Q	S	T
FLOW PATH B-FI						
Equipment Requirement	1	0	.18	.45	-	-
	3	0	.21	.60	-	-
Materials Handling cost in Rs./Month	1	0	2,227	2,550	-	-
	3	0	3,275	3,750	-	-
FLOW PATH B-FII						
Equipment Requirement	1	0	.18	.51	-	1.0
	3	0	.18	.51	-	1.0
Materials Handling Cost in Rs./Month	1	0	2,518	2,880	-	1,640
	3	0	2,518	2,880	-	1,640
Purchase cost of handling equipment	1	0	-	-	-	24,000
	3	0	-	-	-	24,000

Equipment Requirement	1	2	.15	.45	1.0	-
	1	3	.14	.35	1.0	-
	3	1	.14	.35	1.0	-
	3	2	.15	.36	1.0	-
Materials handling cost in Rs./Month	1	2	2,100	2,400	1,350	-
	1	3	1,890	2,160	900	-
	3	1	1,890	2,160	900	-
	3	2	2,100	2,400	1,170	-
Purchase cost of handling Equipment	1	2	-	-	12,000	-
	1	3	-	-	8,000	-
	3	1	-	-	8,000	-
	3	2	-	-	11,000	-

FLOW PATH A-FII

Equipment Requirement	1	2	.24	.54	1.0	-
	1	3	.33	.63	1.0	-
	3	1	.21	.48	1.0	-
	3	2	.24	.54	1.0	-
Materials Handling cost in Rs./Month	1	2	2,217	3,223	1,249	-
	1	3	3,158	4,012	2,403	-
	3	1	1,827	2,730	1,097	-
	3	2	2,217	3,223	1,249	-
Purchase cost of handling equipment	1	2	-	-	11,000	-
	1	3	-	-	16,000	-
	3	1	-	-	10,000	-

First 3 flow paths are considered as Problem - 3.

PROBLEM 5 and 6

(A) ACCEPTABLE LOCATIONS

NEW MACHINE	LOCATION 1	2	3
A	1	0	1
B	1	1	1

(B) ALTERNATE HANDLING SYSTEMS

	A	B	FI	FII	FIII
A	-	-	Q,T	P,Q,S	-
B	P,Q	-	P,Q,S	P,Q,T	P,Q,S

(C) OTHER DATA

	LOCATION		HANDLING SYSTEM			
	A	B	P	Q	S	T
FLOW PATH A-FI						
Equipment Requirement	1	0	-	.30	-	1.0
	3	0	-	.50	-	1.0
Materials handling cost in Rs./Month	1	0	-	800	-	700
	3	0	-	1,806	-	971
Purchase cost	1	0	-	-	-	20,000
	3	0	-	-	-	24,000

FLOW PATH A-FII

Equipment Requirement	1	0	.40	.70	1.0	-
	3	0	.40	.70	1.0	-
Materials handling cost in Rs./Month	1	0	841	1,484	563	-
	3	0	841	1,484	563	-
Purchase cost	1	0	-	-	12,000	-
	3	0	-	-	12,000	-

FLOW PATH B-A

Equipment Requirement	1	2	.60	.70	-	-
	1	3	.20	.30	-	-
	3	1	.10	.10	-	-
	3	2	.40	.50	-	-
Materials handling cost in Rs./Month	1	2	514	761	-	-
	1	3	410	475	-	-
	3	1	171	242	-	-
	3	2	209	394	-	-

FLOW PATH B-FI

Equipment Requirement	1	2	.70	.90	-	1.0
	1	3	.20	.50	-	1.0
	3	1	.40	.70	-	1.0
	3	2	.40	.70	-	1.0
Materials handling cost in Rs./Month	1	2	150	251	-	113
	1	3	116	150	-	60
	3	1	130	201	-	81
	3	2	130	201	-	81

Purchase cost of handling equipment	1	2	-	-	-	15,000
	1	3	-	-	-	10,000
	3	1	-	-	-	12,000
	3	2	-	-	-	12,000

FLOW PATH B-FII

Equipment Requirement	1	2	.20	.40	1.0	-
	1	3	.30	.50	1.0	-
	3	1	.30	.50	1.0	-
	3	2	.20	.40	1.0	-
Materials handling cost in Rs./Month	1	2	760	840	600	-
	1	3	810	905	765	-
	3	1	810	905	765	-
	3	2	760	840	600	-
Purchase cost of handling equipment	1	2	-	-	12,000	-
	1	3	-	-	15,000	-
	3	1	-	-	15,000	-
	3	2	-	-	12,000	-

FLOW PATH B-FIII

Equipment Requirement	1	2	.20	.40	1.0	-
	1	3	.30	.50	1.0	-
	3	1	.30	.50	1.0	-
	3	2	.20	.40	1.0	-
	3	2	.20	.40	1.0	-

Materials handling cost in Rs./Month	1	2	760	840	600	-
	1	3	810	905	765	-
	3	1	810	905	765	-
	3	2	760	840	600	-
Purchase cost of handling equipment	1	2	-	-	12,000	-
	1	3	-	-	15,000	-
	3	1	-	-	15,000	-
	3	2	-	-	12,000	-

INVESTMENT - 1,00,000

The first 5 Flow paths are considered as Problem - 5

PROBLEM 7 and 8

(A) ALTERNATE LOCATIONS

NEW MACHINE	LOCATION	1	2	3	4	5
A		0	0	1	1	1
B		1	1	1	0	0
C		1	0	1	0	0

(B) HANDLING SYSTEM ALTERNATIVE

NEW MACHINE	NEW OR EXISTING MACHINE	A	B	C	FI	FII	FIII
A		-	-	Q	X	P,Q	X
B		-	-	P,Q,T	P,S	X	X
C		-	-	-	P,Q,T	P,Q	P,Q,S

Handling system specifications are same as Problem - 1.

FLOW PATH B-C

Equipment Requirement	1	2	0	.10	.20	-	1.0
	1	3	0	.40	.60	-	1.0
	3	1	0	.20	.30	-	1.0
	3	2	0	.10	.20	-	1.0
Materials handling cost in Rs./Month	1	2	0	3,673	4,624	-	2,470
	1	3	0	3,878	5,060	-	2,995
	3	1	0	3,720	4,862	-	2,520
	3	2	0	3,673	4,624	-	2,470
Purchase cost of materials handling equipment	1	2	0	-	-	-	13,000
	1	3	0	-	-	-	14,000
	3	1	0	-	-	-	11,000
	3	2	0	-	-	-	15,000

FLOW PATH B-FI

Equipment Requirement	1	2	0	.10	-	1.0	-
	1	3	0	.20	-	1.0	-
	3	1	0	.20	-	1.0	-
	3	2	0	.10	-	1.0	-
Materials handling cost in Rs./month	1	2	0	5,015	-	3,514	-
	1	3	0	5,496	-	3,533	-
	3	1	0	4,859	-	3,244	-
	3	2	0	5,566	-	3,798	-

Purchase cost of handling equipment.	1	2	0	-	-	18,000	-
	1	3	0	-	-	20,000	-
	3	1	0	-	-	15,000	-
	3	2	0	-	-	17,000	-

FLOW PATH A-C

Equipment Requirement	1	2	3	-	.20	-	-
	1	2	4	-	.30	-	-
	1	2	5	-	.40	-	-
	1	3	4	-	.30	-	-
	1	3	5	-	.60	-	-
	3	1	4	-	.50	-	-
	3	1	5	-	.30	-	-
	3	2	4	-	.50	-	-
	3	2	5	-	.30	-	-
Handling cost	1	2	3	-	2,216	-	-
	1	2	4	-	2,317	-	-
	1	2	5	-	2,417	-	-
	1	3	4	-	2,317	-	-
	1	3	5	-	4,126	-	-
	3	1	4	-	3,527	-	-
	3	1	5	-	3,070	-	-
	3	2	4	-	3,527	-	-
	3	2	5	-	3,070	-	-

FLOW PATH A-FII I

Equipment requirement	1	2	3	.60	.80	-	-
	1	2	4	.40	.60	-	-
	1	2	5	.70	.90	-	-
	1	3	4	.40	.60	-	-
	1	3	5	.70	.90	-	-
	3	1	4	.40	.60	-	-
	3	1	5	.70	.90	-	-
	3	2	4	.40	.60	-	-
	3	2	5	.70	.90	-	-
Materials handling cost in Rs./Month	1	2	3	350	641	-	-
	1	2	4	259	556	-	-
	1	2	5	454	701	-	-
	1	3	4	259	556	-	-
	1	3	5	454	701	-	-
	3	1	4	259	556	-	-
	3	1	5	454	701	-	-
	3	2	4	259	556	-	-
	3	2	5	454	701	-	-

First 5 flow path of this problem is considered as PROBLEM - 6

APPENDIX - 4

SAMPLE OUTPUT FOR DYNAMIC PROGRAMMING PROCEDURE

PROBLEM - 2

A sample output for Problem - 2, data for which are given in Appendix - 3 is illustrated in this Appendix.

INCREMENT IN DIRECTION - 1 = Rs. 1,000

INCREMENT IN DIRECTION - 2 = .03

INCREMENT IN DIRECTION - 3 = .03

BLOCK DIAGONAL POINTS 1	2	HANDLING COST	HANDLING SYSTEM
FLOW PATH A-FI LOCATION OF A - 1			
(0, 0, 0)	(5, 6, 15)	99,999	0
(5, 0, 0)	(60, 6, 34)	2,550	2
(0, 6, 0)	(5, 34, 15)	2,227	1
(0, 0, 15)	(5, 6, 34)	2,550	2
(60, 0, 0)	(85, 34, 34)	2,227	1
(5, 6, 0)	(60, 34, 34)	2,227	1
(0, 6, 15)	(5, 34, 34)	2,227	1

LOCATION OF A-2

(0, 0, 0)	(5, 7, 20)	99,999	0
(5, 0, 0)	(60, 7, 34)	3,750	2
(0, 7, 0)	(5, 34, 20)	3,275	1
(0, 0, 20)	(5, 7, 34)	3,750	2
(60, 0, 0)	(85, 34, 34)	3,275	1
(5, 7, 0)	(60, 34, 34)	3,275	1
(0, 7, 20)	(5, 34, 34)	3,275	1

FLOW PATH A-FII

LOCATION OF A	MONTHLY HANDLING COST	SYSTEM SELECTED FLOW PATH A-FI	SYSTEM SELECTED FLOW PATH A-F1
1	4,190	2	4
2	5,390	2	4

OVERALL OPTIMAL POLICY

LOCATION OF A	MONTHLY HANDLING COST	SYSTEM SELECTED FLOW PATH-1	SYSTEM SELECTED FLOW PATH-2
1	4190	2	4

[redacted]